Monotoring aboveground biomass from L-VOD

J-P Wigneron et al.,

INRAE Bordeaux (IB) Remote Sensing Lab

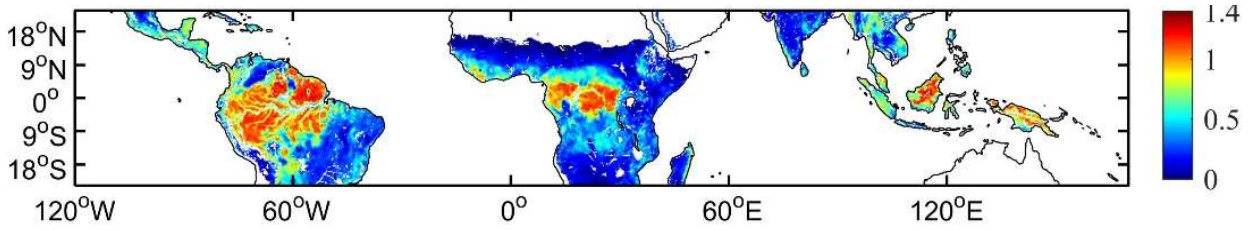
https://ib.remote-sensing.inrae.fr/

With all the INRAE Bordeaux team : Frédéric Frappart, Xiaojun Li, Xiangzhuo Liu, Huan Wang, Zanpin Xing, Mengjia Wang, Hongliang Ma, Yuqing Liu etc.

and Philippe Ciais, Lei Fan, Martin Brandt, Rasmus Fensholt, Hui Yang, Yuanwei Qin, Xiangming Xing, etc.

JPL CCS workshop: Science of 10-km L-band Radiometry, Oct. 2023

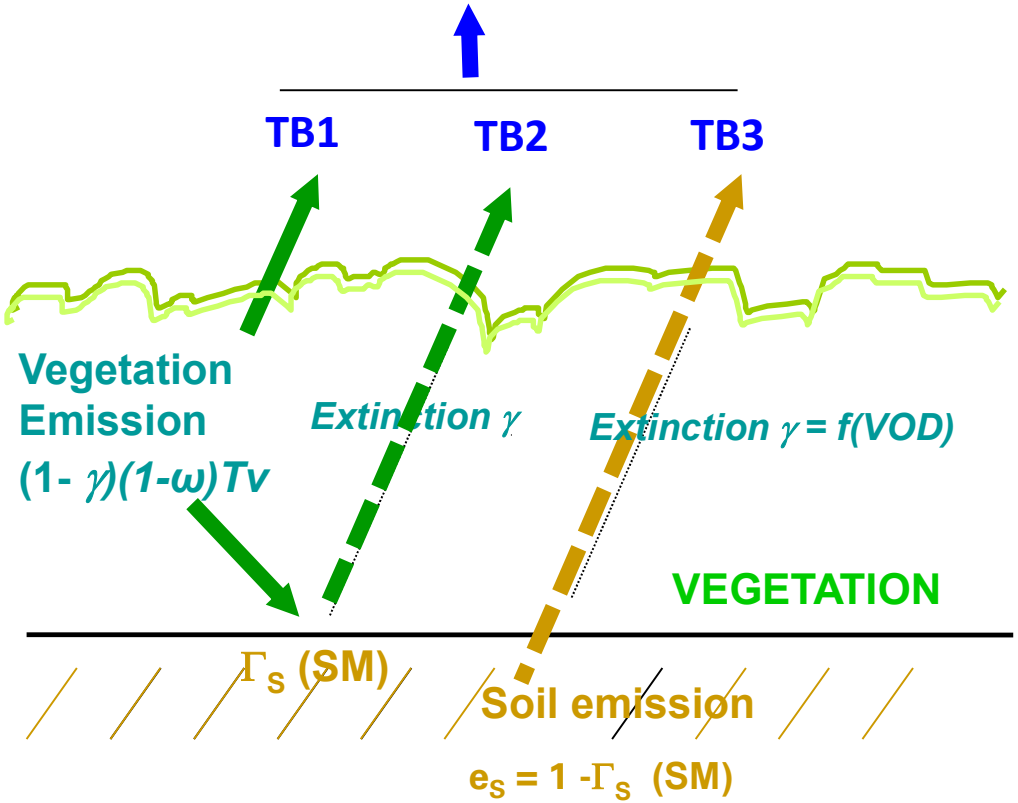
- what is VOD?
- 2-parameter retrieval of SM and VOD
- L-VOD *vs* BIOMASS, Evaluation / Validation
- Applications of L-VOD to vegetation monitoring



Passive Microwave Observations

Brightness temperature is sensitive to both SM and VOD

$$TB_{veg} = (1 - e^{-VOD/\cos(\theta)})(1-\omega)T_{veg}(1+\Gamma_{soil}e^{-VOD/\cos(\theta)})$$



VOD ~ vegetation extinction effects

$\gamma = \exp(-VOD_{NADIR}/\cos(\theta))$, extinction factor

Key parameters of TB:

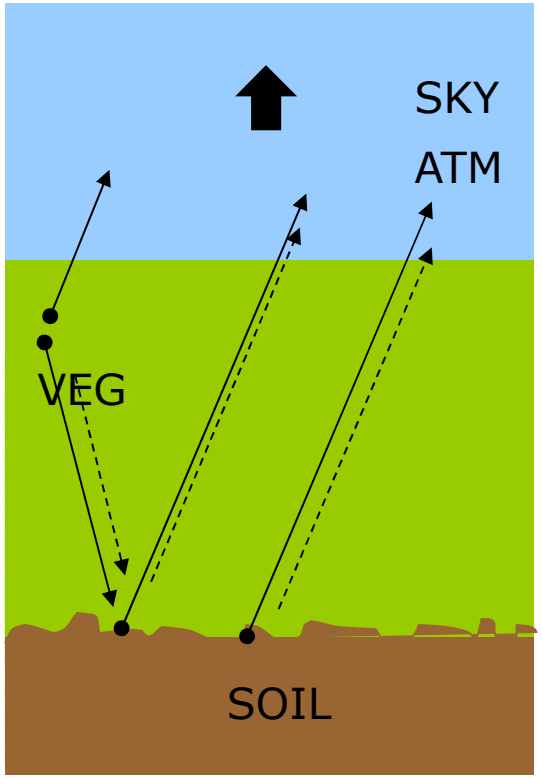
-Soil moisture (SM) $\rightarrow \Gamma_s$
and roughness soil texture

-VOD $\rightarrow \gamma$ **(emission & extinction)**
and vegetation structure

-Temperature (soil , vegetation)

-ω : canopy type structure / moisture content (%)

Vegetation Optical Depth (VOD)



VOD = b . VWC (kg/m2) VWC= veg. water cont (kg/m2)

VOD ~ VWC = Bs. Mg / (1-Mg)

where,

-Mg = moisture content (%) ~ vegetation water status (φ)

-Bs = Dry biomass (kg/m2)

So, decoupling Biomass & φ

is required for monitoring either Biomass or φ

2-Parameter (SM, L-VOD) Retrievals

L-VOD = VOD at L-band

Wigneron et al., 1993, 1995, 2007, over crop fields
Wigneron et al., 2000, based on simulated SMOS observations
Fernandez Moran, 2017, Li et al., 2020, Wigneron et al., 2021, applied to SMOS-IC

1-Parameter retrievals of soil moisture (SM)

[Jackson et al., 2007]

1-P retrievals of SM

(Jackson et al., 2007)

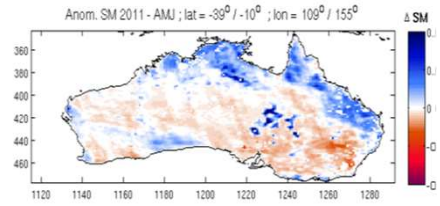
Still used in SCA-V SMAP algorithm

LAI or NDVI maps (climatology)

VOD = b . VWC (NDVI)

Mono-angular H & V TB

1-P retrievals



SM map

- **ω : tabulated from vegetation type maps**
- **soil & vegetation temperature (model)**
- **soil texture (ancillary data as FAO maps)**

2-P method: multiangular observations allow 2-Parameter retrievals of SM and L-VOD

[Wigneron et al., 1993, 1995-2007]

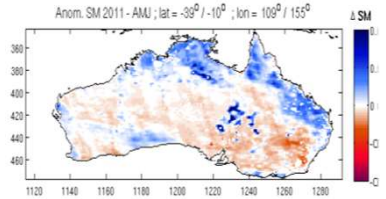
Multi-angular
&/or Multi-orbit TB

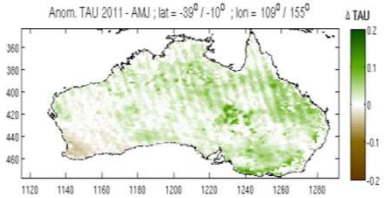
Wigneron et al., 1993, 1995, 2000
SMOS-IC

2-P retrievals

SM

VOD





Hypothesis made in multi-orbit retrievals:
VOD varies slowly in time

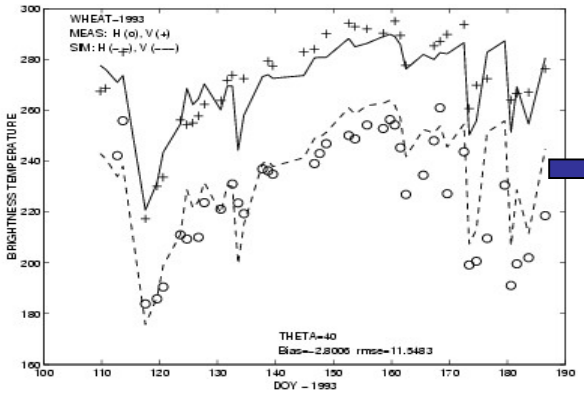
Advantage of the 2-P method:

(1) accuracy: no need for rough estimate of VOD from NDVI
(2) VOD = output of the algorithm = interesting veg. parameter

Results of Wigneron et al. (RSE, 2000), physical section of the SMOS project submitted to ESA Earth Explorer mission, with a SMOS launch ten years later in 2009

Wigneron, J.P., Waldteufel, P., Chanzy, A., Calvet, J.C., Kerr, Y., 2000.
Two-dimensional microwave interferometer retrieval capabilities over land surfaces (SMOS mission). Remote Sens. Environ. 73, 270–282.

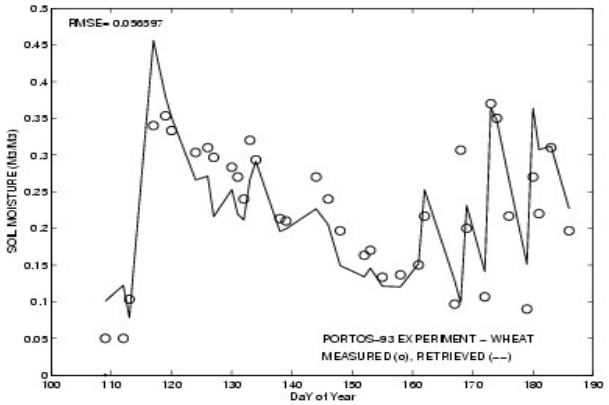
1993-1995: Experimental evaluation of 2-P retrievals from in situ data



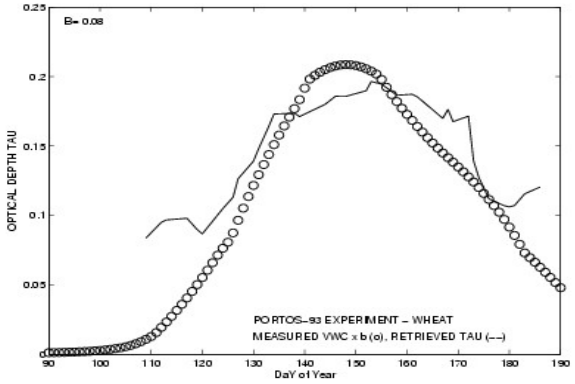
Multi-angular TB_H, TB_V = f(time)

2-P retrievals

Retrieved SM



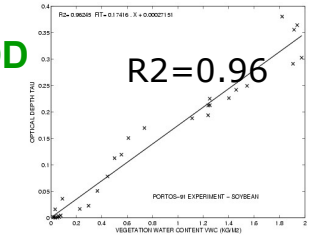
Retrieved L-VOD



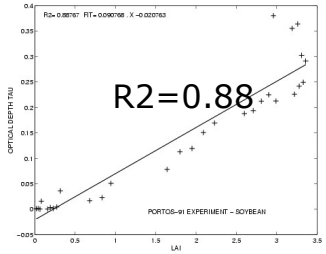
time

Retrieved VOD = b VWC = b' LAI

VOD



VWC



LAI

Wigneron et al., 1993 1995 : first papers showing the possibility of retrieving both SM and biomass

Wigneron J.-P., et al., 'A simple algorithm to retrieve soil moisture and vegetation biomass using passive microwave measurements over crop fields', Remote Sens. Environ. 51:331-341, 1995.

2000 (SMOS preparation): theoretical evaluation of of 2-P retrievals applied to multi-angular satellite observations

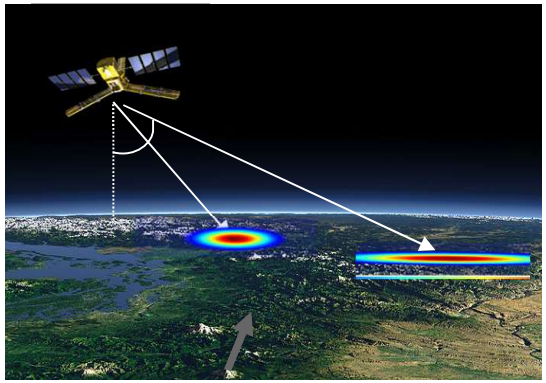
SMOS

Y-shape 8-m deployed interferometric antenna

►Multi-angular L-band observations (0-60deg)
► H and V polarizations

-res ~ 25km, daily
-Goal in SM: ~ 0.04 m3/m3

►Launch: Dec. 2009: ~ a 11-year data set



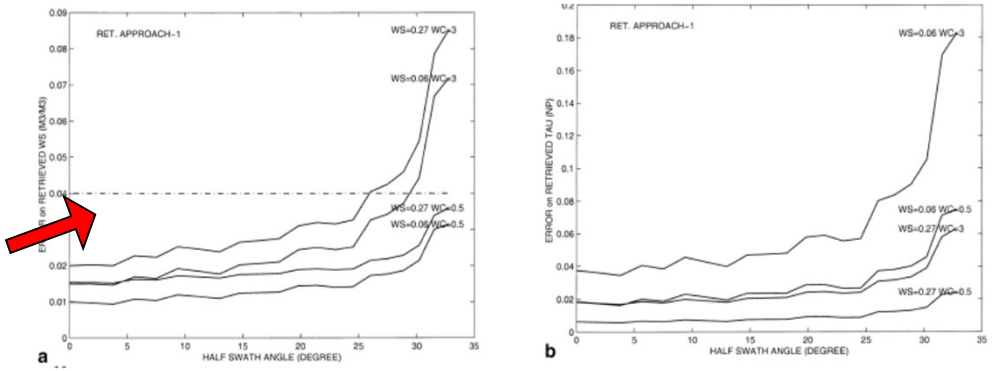
Multi-angular, multi-orbit SMOS TB

2-P retrievals

Hypothesis: VOD varies slowly in time

SM **VOD**

Error in SM < 0.04 m^3/m^3



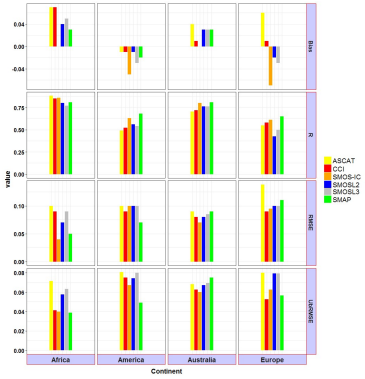
Errors in retrievals vs Multi-angular capability
(Wigneron et al., 2000)

Wigneron J.-P., et al., 'Two-D microwave interferometer retrieval capabilities of over land surfaces (SMOS Mission)', Remote Sens. Environ., 73:270-282, 2000.

VOD product evaluation

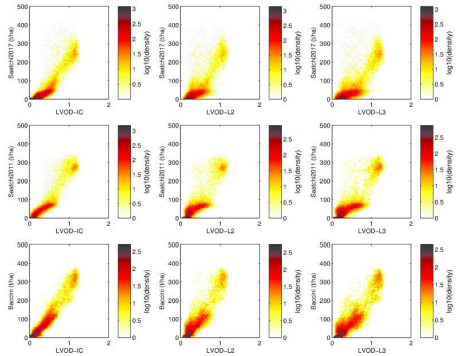
Validation can be stronger : using 2P retrievals, evaluation of one SMAP/SMOS product can be based on both L-VOD and SM

► SM:



Direct evaluation *vs*
in situ (ISMN) and modelled SM

► L-VOD



Indirect evaluation:

spatial & temporal correlation with vegetation indices

Biomass maps (Baccini, Saatchi, CCI Biomass, Globbiomass), LAI, NDVI, X-VOD

L-VOD Vs BIOMASS, Evaluation / Validation

To decouple effects of Water Status & Biomass, 2 assumptions are used:

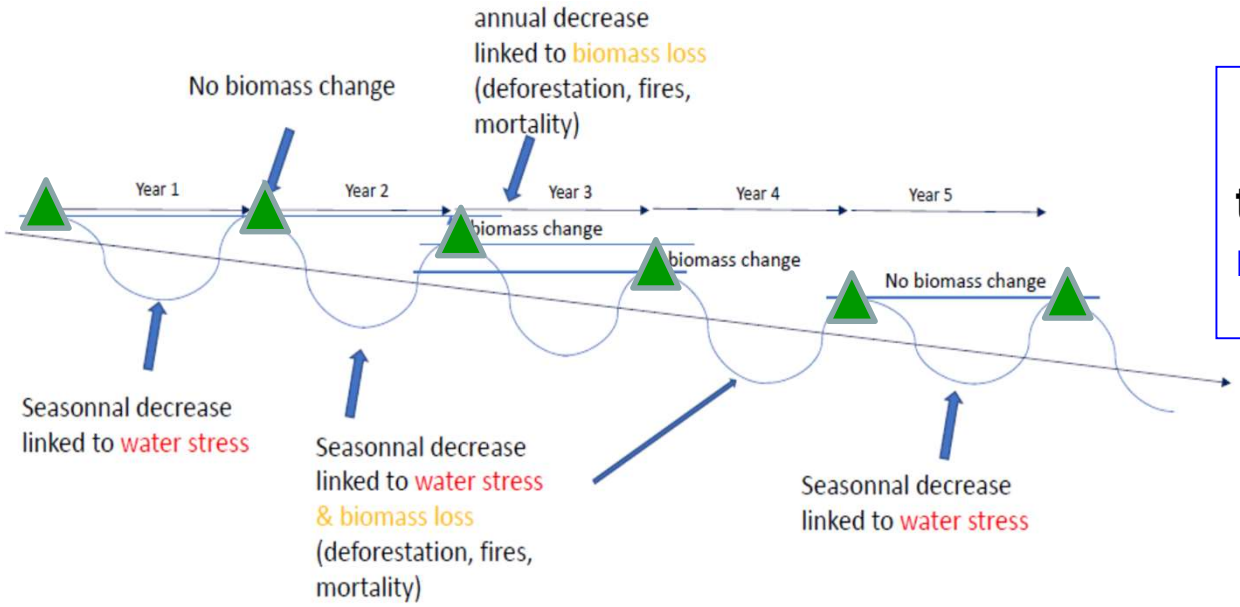
VOD ~ VWC ~ Bs . Mg/(1-Mg)

(1) yearly average (Av) of Mg is ~ constant from year to year:

-> Yearly Av(VOD) = proxy of Biomass (Liu et al., 2013; Brandt et al., 2018)

(2) Max (Mg), associated to wet conditions, is ~constant from year to year

-> Yearly VOD-wet = proxy of Biomass (Qin et al., 2020)



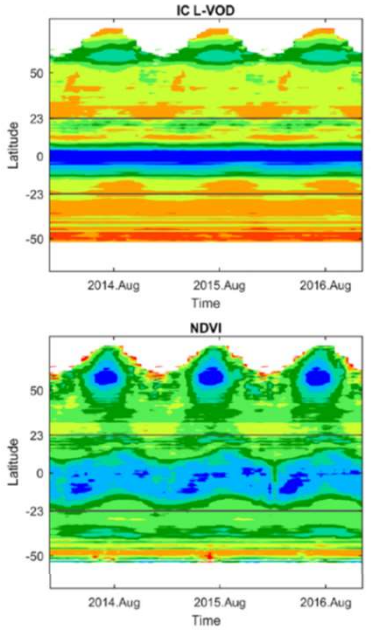
Time variations in L-VOD: annual cycle over 6 years

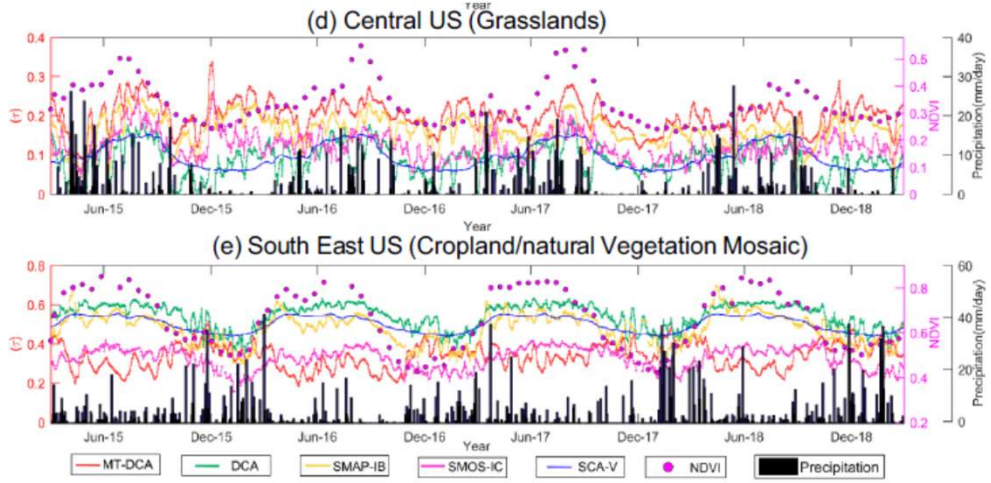
▲ = VOD-wet associated to wet conditions is mostly related to biomass changes

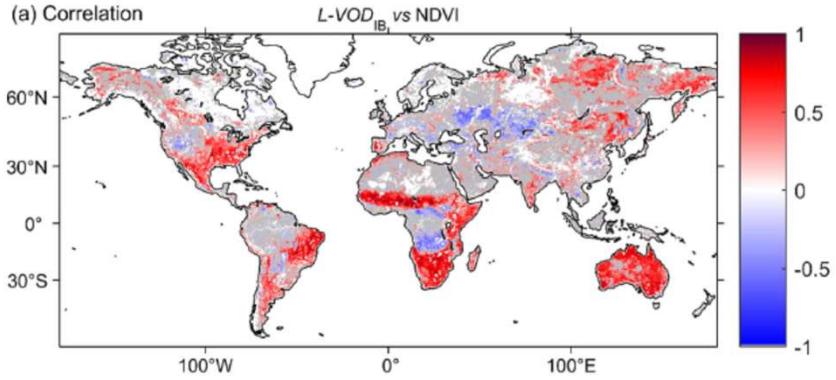
Evaluating VOD indices vs vegetation dynamics : not a single criterion, but a combination of criteria:

- **Spatio-temporal agreement with optical indices, C- and X-VODs** (correlation should be stronger in low vegetation areas where there is low saturation in those vegetation indices)

-Hovmöller diagrams of VODs, NDVI, LAI
-Map of temporal correlation (phenology)
-Analysis of temporal signatures on specific sites

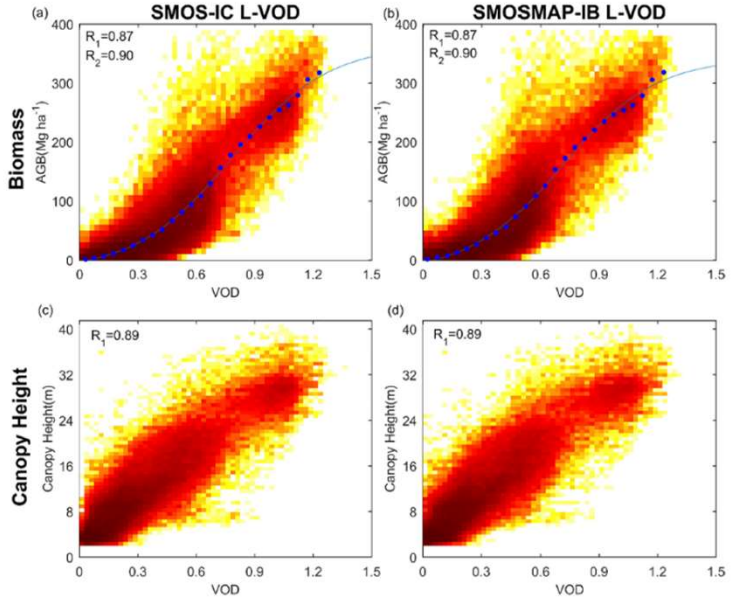




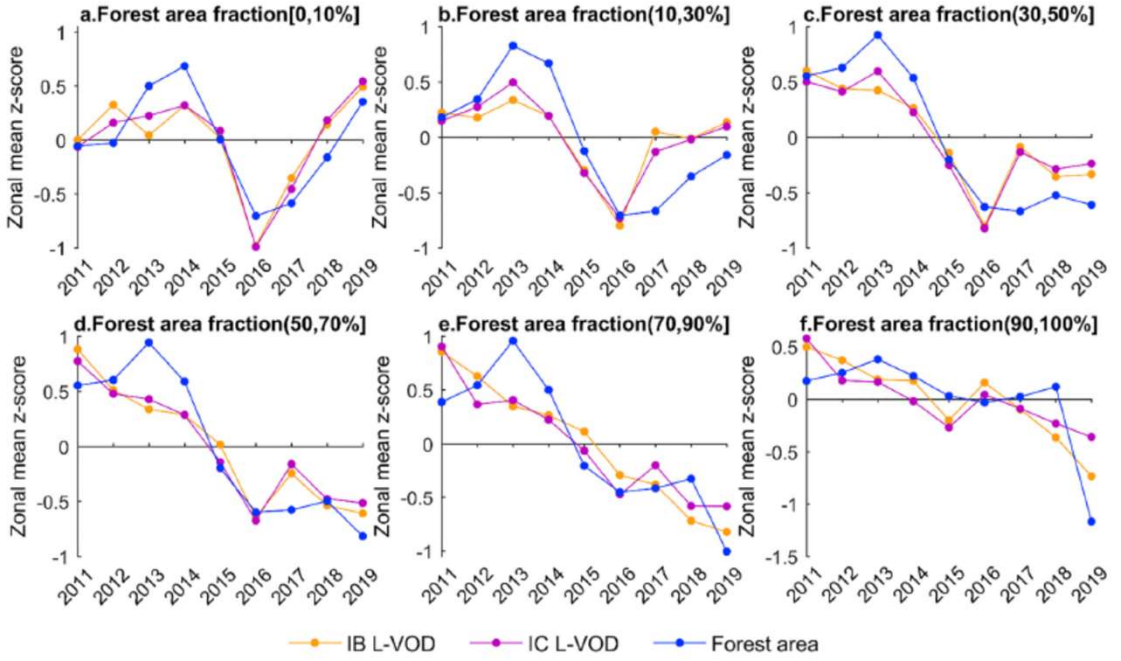


Evaluating VOD indices: not a single criterion, but a combination of criteria

Spatial correlation VOD vs Biomass and Height

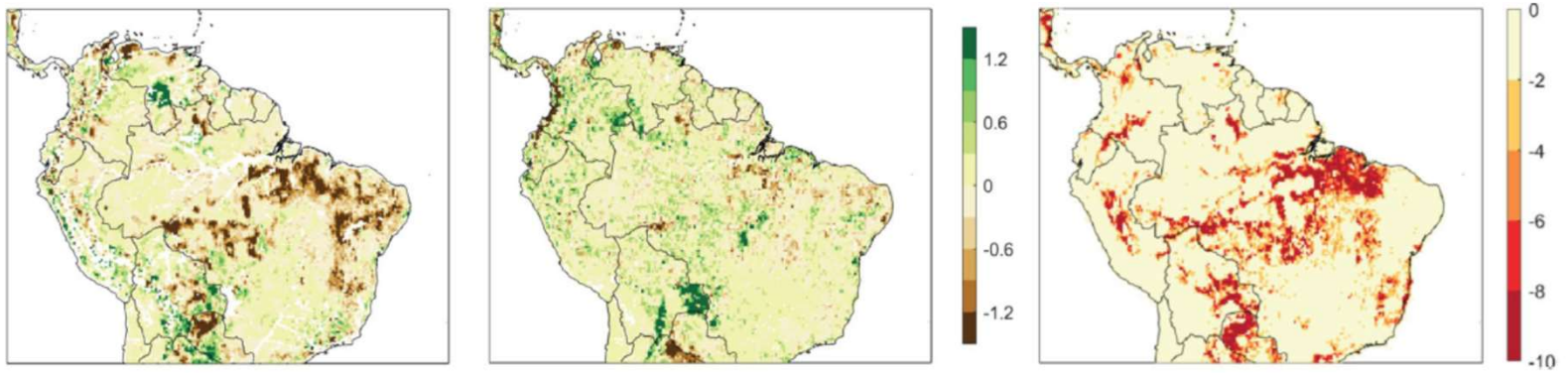


Temporal correlation vs GGW forest loss = proxy of biomass loss in the Amazon basin



Evaluating temporal changes in VOD derived biomass vs reference biomass products? : To the best of our knowledge, there is no reference product of this type.

Konings et al. (GRL , 2021) used biomass data set from Xu et al. to evaluate L-VOD capabilities in monitoring biomass changes , but is Xu et al. a « reference » product?



L-VOD derived biomass changes in South America (2010-2019)

Biomass changes from Xu et al. (2010-2019)

Forest loss fraction from GFW (2010-2019)

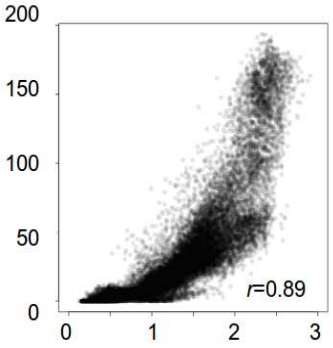
A quick review of a few applications of L-VOD for monitoring water content and biomass (supported by C- and X-VOD)

Satellite passive microwaves reveal recent climate-induced carbon losses in African drylands

Martin Brandt[1*], Jean-Pierre Wigneron[2*], Jerome Chave[3], Torbern Tagesson[1], Josep Penuelas[4,5], Philippe Ciais[6], Kjeld Rasmussen[1], Feng Tian[1], Cheikh Mbow[7], Amen Al-Yaari[2], Nemesio Rodriguez-Fernandez[8], Guy Schurgers[1], Wenmin Zhang[1,9], Jinfeng Chang[6], Yann Kerr[8], Aleixandre Verger[4,5], Compton Tucker[10], Arnaud Mialon[8], Laura Vang Rasmussen[1], Lei Fan[2] and Rasmus Fensholt[1]

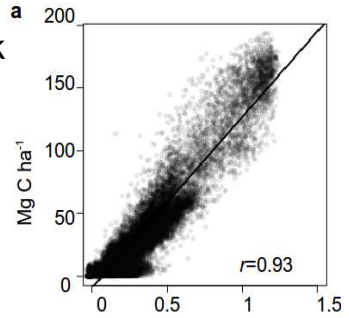
Brandt et al., NEE (2018)

C-stock Baccini



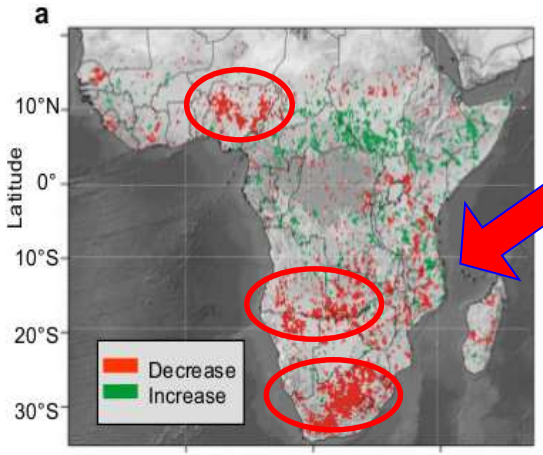
X-VOD

C-stock Baccini

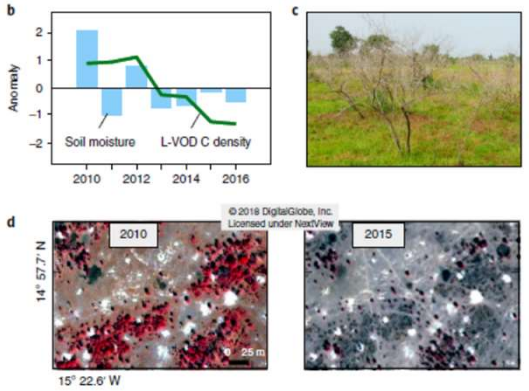


SMOS-IC L-VOD

- spatial calibration L-VOD / C-stocks in 2011
- ''space for time'' substitution: use of the spatial calibration to monitor time-changes in C-stocks in Africa



Extreme 2014-2016 dry conditions impacted carbon stocks in drylands; Africa, 2010-2016

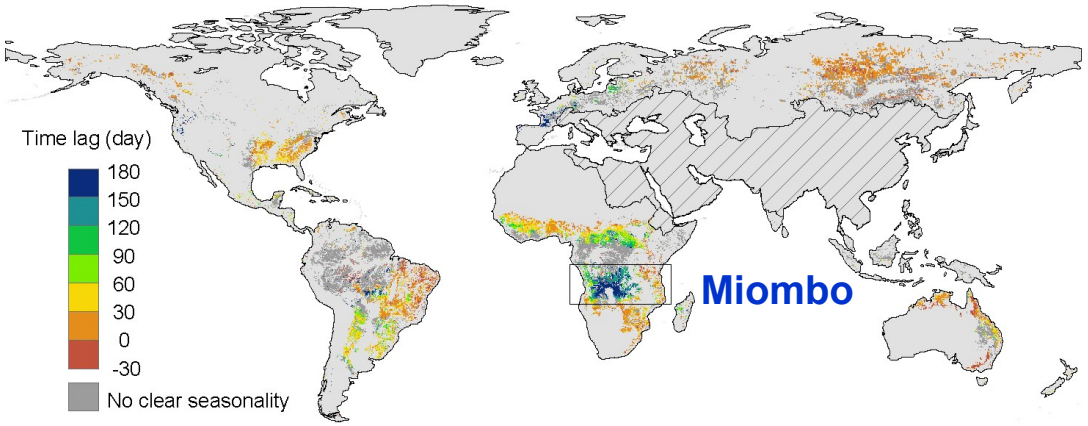


Brandt et al., 2018
© M. Brandt, University of Copenhagen

Coupling of ecosystem-scale plant water storage and leaf phenology observed by satellite

Feng Tian[1,2*], Jean-Pierre Wigneron[3*], Philippe Ciais[4], Jérôme Chave[5], Jérôme Ogée[3], Josep Peñuelas[6,7], Anders Ræbild[2], Jean-Christophe Domec[8], Xiaoye Tong[2], Martin Brandt[2], Arnaud Mialon[9], Nemesio Rodriguez-Fernandez[9], Torbern Tagesson[1,2], Amen Al-Yaari[3], Yann Kerr[9], Chi Chen[10], Ranga B. Myneni[10], Wenmin Zhang[2], Jonas Ardö[1] and Rasmus Fensholt[2]

Tian et al., NEE (2018)



Time lag between L-VOD and LAI
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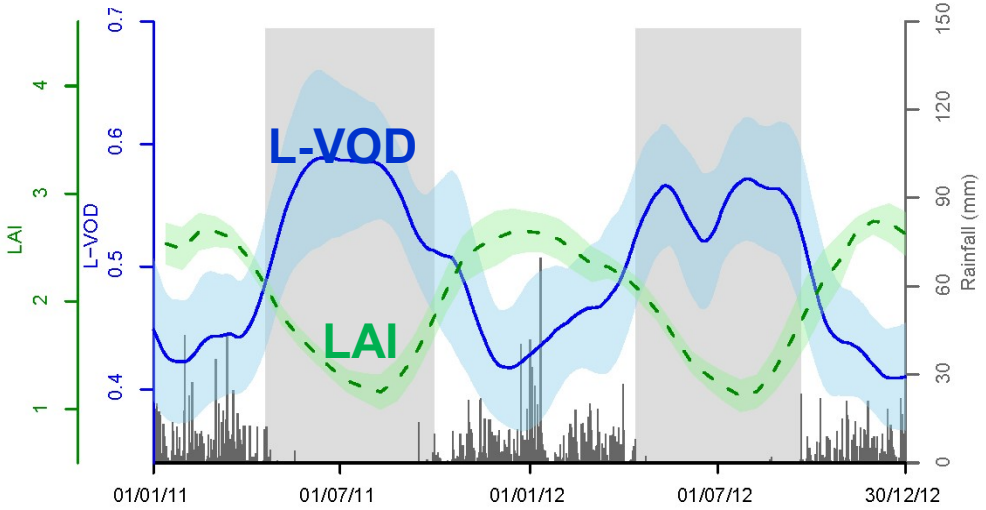
Pre-rain Miombo forest
© C. Ryan, University of Edinburgh

A high temporal decoupling between plant water storage and LAI in dry Tropical forests (especially in Miombo)



Time variation in L-VOD and LAI (Miombo)
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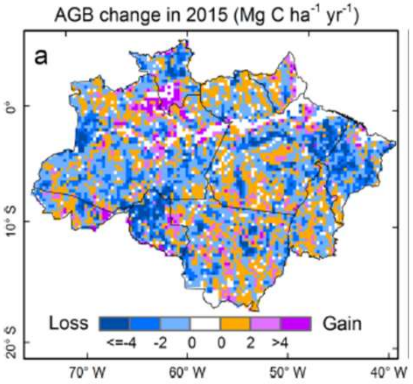
Extension to the whole tropics

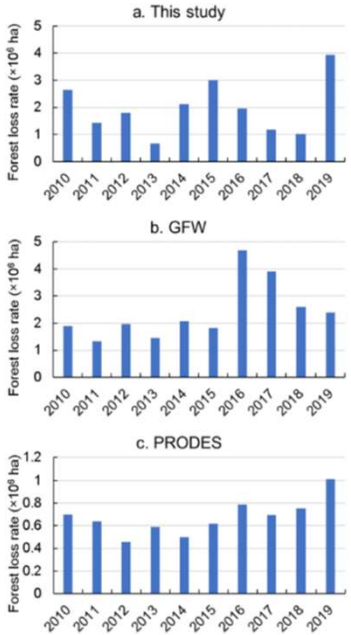
Carbon loss from forest degradation exceeds that from deforestation in the Brazilian Amazon

Qin et al., NCC (2023)



-L-VOD → yearly biomass (AGB)
(resolution = 25km, INRAE-Bdx)

-PALSAR/MODIS forest area
(resolution= 500m, Oklahoma)



PALSAR/MODIS

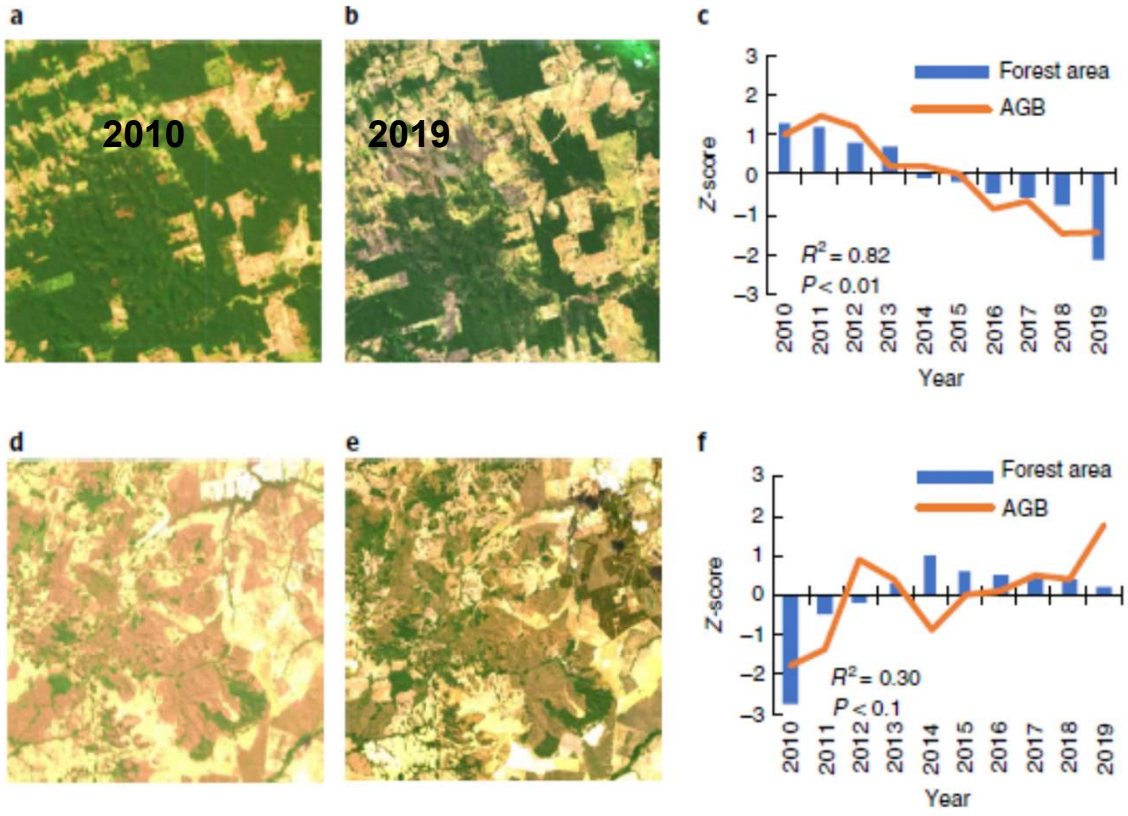
Global Forest Watch (Hansen)

PRODES

Illustration over 2 pixels
(a) Losses in biomass and FAF
(b) Gains in biomass and FAF

Landsat Images (30m)

AGB and FAF (25km)



Degradations vs deforestation over 2010 - 2019

We used $AGB_{Saatchi}$ = high resolution AGB map but static

Losses FAF x $AGB_{Saatchi}$ (over each pixel) → **AGB losses due to deforestation (∆AGB_D)**

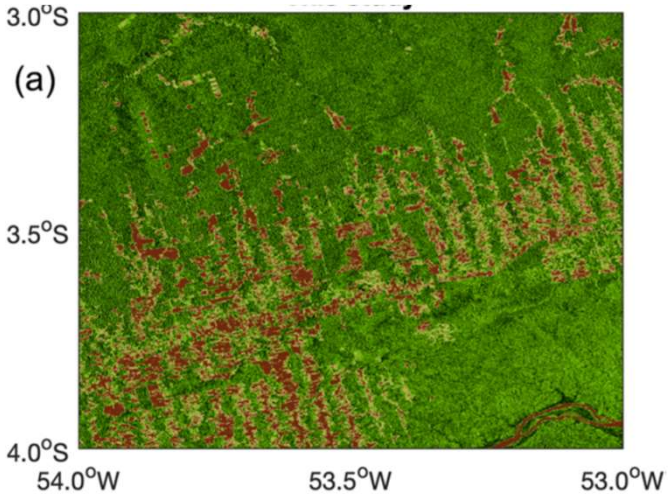
L-VOD derived Losses → **total AGB losses (∆AGB_T)**

AGB losses from degradations:

∆AGB_T - ∆AGB_D

Degradations represent 70% of the biomass losses; deforestation 30%

degradations = biomass losses in forest due to degradations close to clearcuts (edge effects), selective logging, isolated fires, understory fires, and mortality (droughts, insects, etc.)



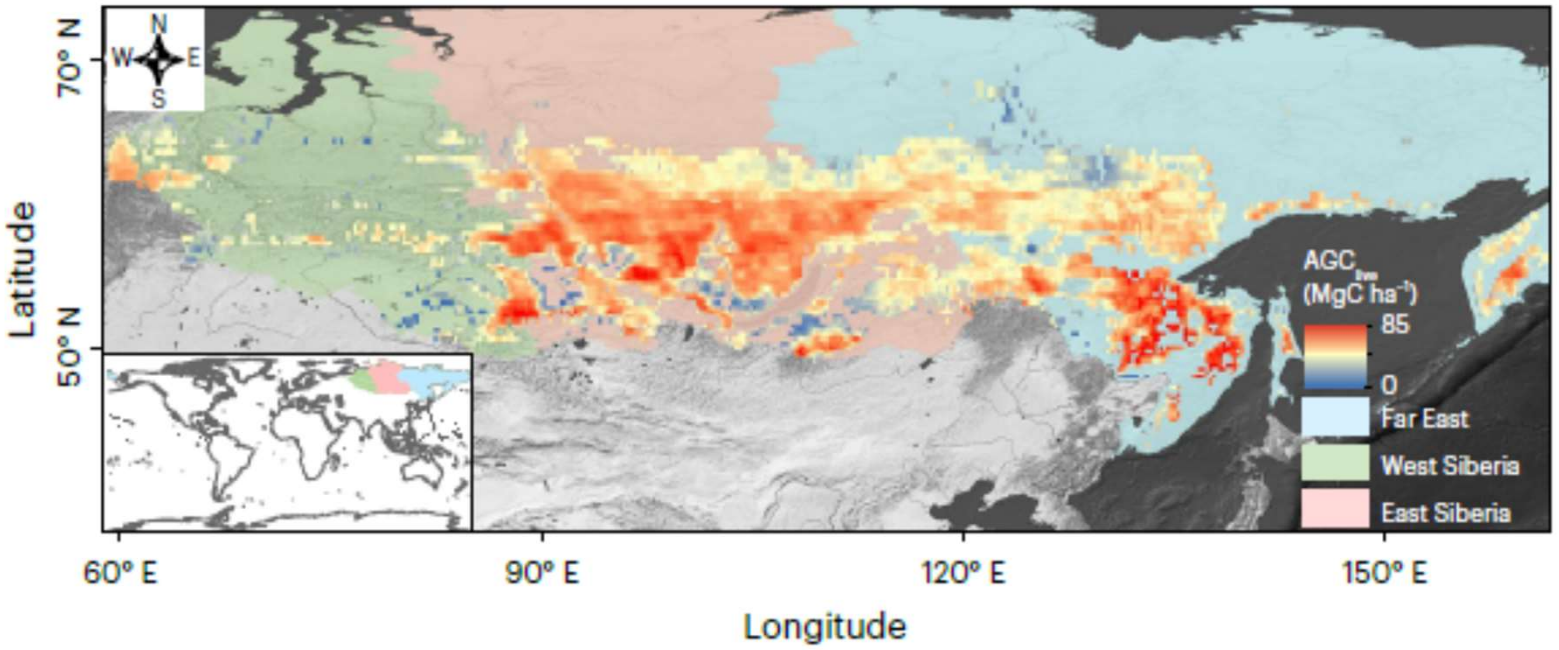
nature geoscience

Article

https://doi.org/10.1038/s41561-022-01087-x

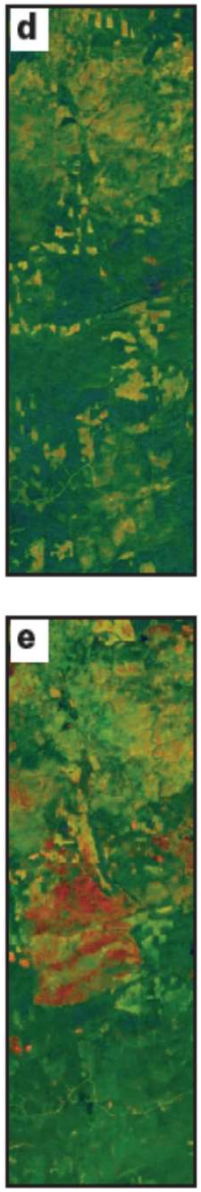
Siberian carbon sink reduced by forest disturbances

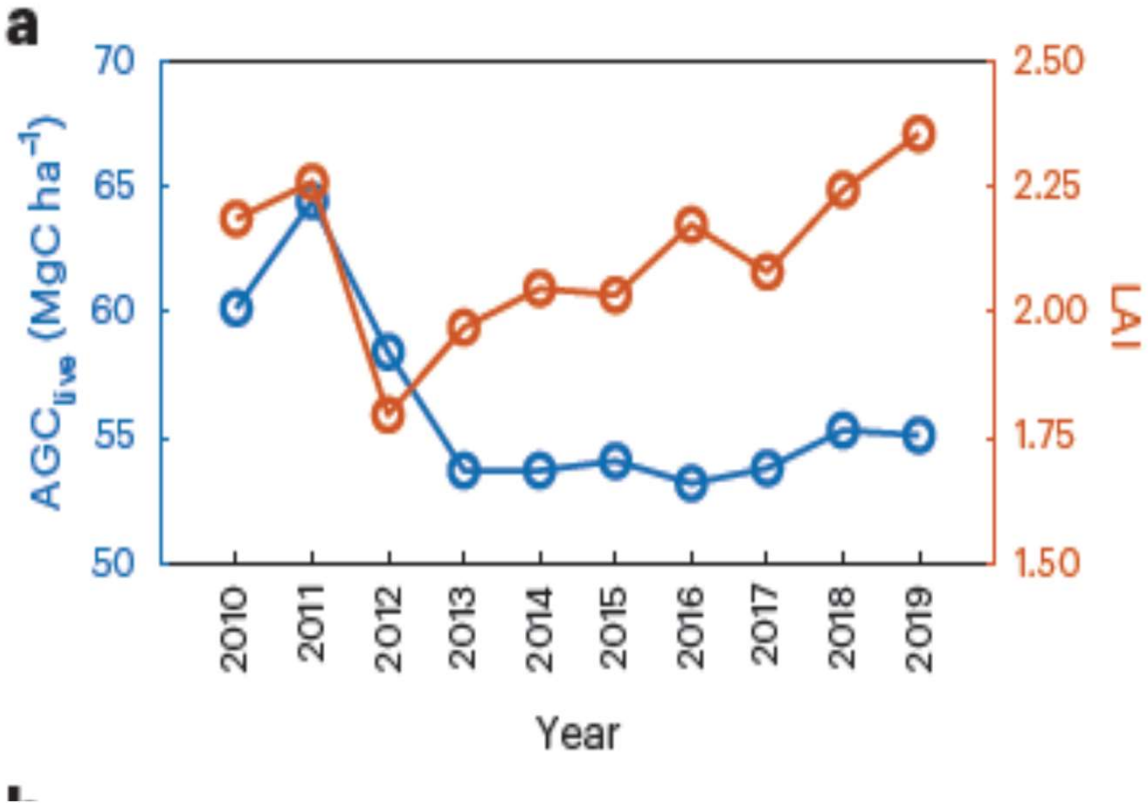
Fan et al., (2023)



Recovery in L-VOD *vs* LAI after a large fire event:

LAI reflects greening not biomass





Fan et al., (2023)

nature geoscience

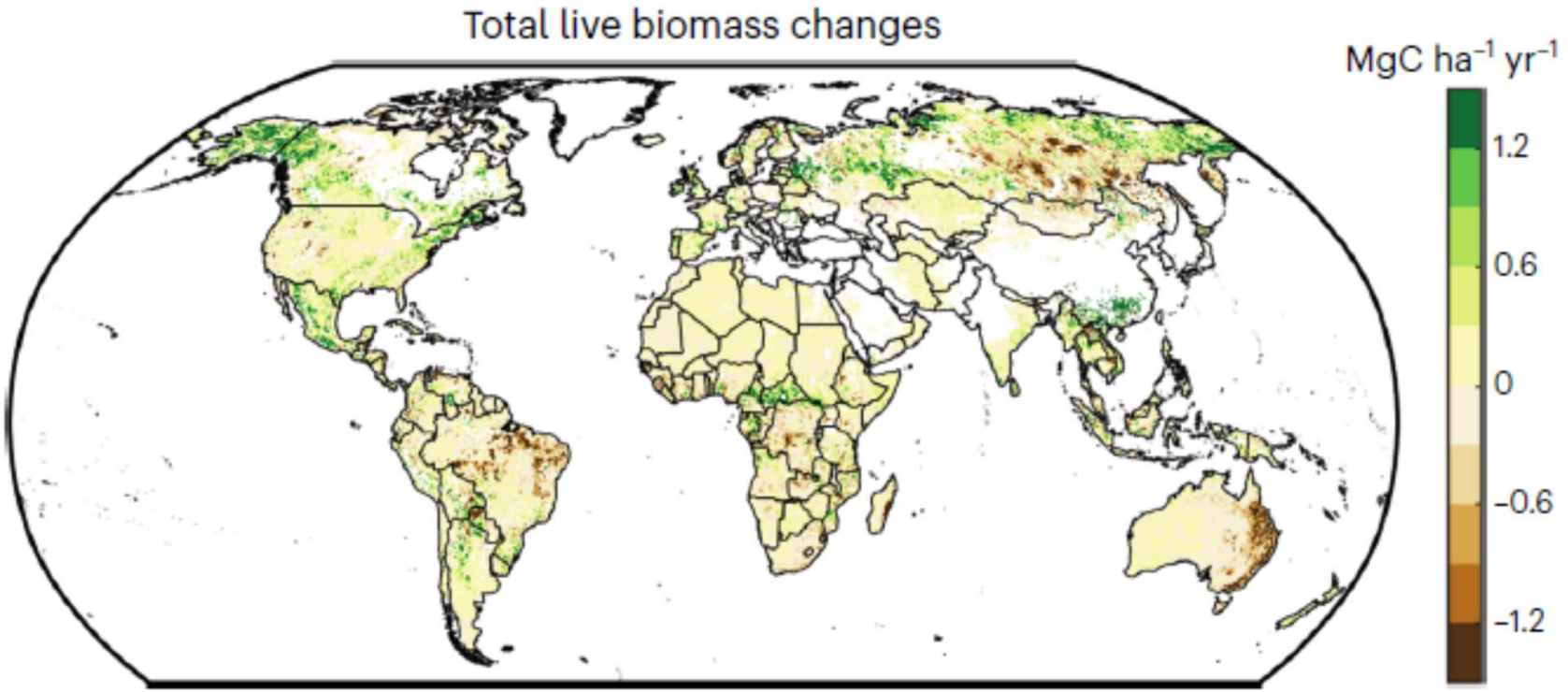
Article

https://doi.org/10.1038/s41561-023-01274-4

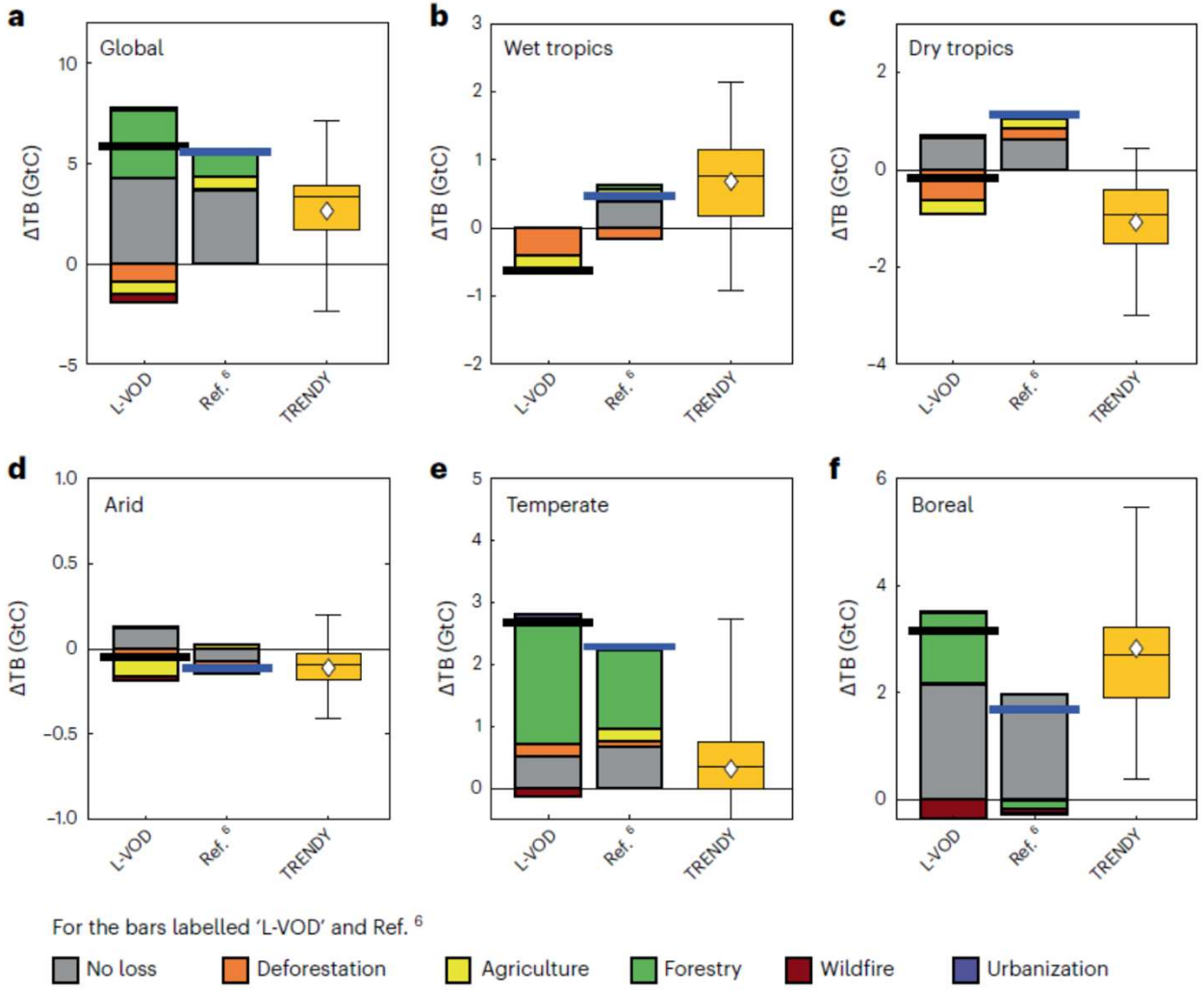
Global increase in biomass carbon stock dominated by growth of northern young forests over past decade

Yang et al., (2023)

Sink in total vegetation biomass (AGB & BGB) = 500 Millions Tons /year



Main Sinks are found in Temperate / Boreal regions, while the tropics = a low C sources, in contradiction with models that do not account for demography, and Xu et al. (optical, high freq. MW)



Conclusion perspectives

Perpectives & ongoing studies

-L-VOD is a unique vegetation indice to monitor the vegetation biomass, water content and phenology well supported by C-VOD and X-VOD (LPDR is best for biomass) in non-dense vegetated areas

many notable L-VOD applications that have recently boosted ESA's scores in the Nature / Science journals: LVOD products are useful !

-Decoupling the effects of biomass/ moisture content = important but doable

Recently, a correction based on proxies of the vegetation moisture content showed a low impact on C trends (Yang et al., PNAS, 2022, Li et al., in prep.)

-Developing disaggregation approach (makes attribution much easier):

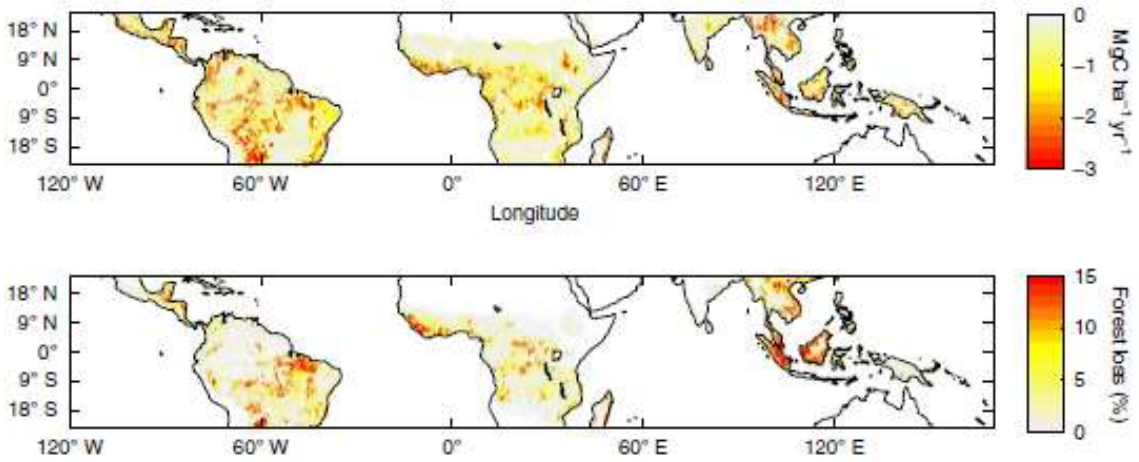
Ongoing

-Use of multi-angular vs mono-angular to retrieve SM and VOD?

Multi-angular has more capabilities but SMOS TB is much noisier than SMAP
SMOS and SMAP L-VOD temporal trends are generally very similar

THANK YOU!

IB INRAE Bordeaux: new tools for monitoring C-stocks



2010-2017, Fan et al., 2019

Carbon losses
(SMOS-IC L-VOD)

Deforestation
(forest fraction
GFW)

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https://ib.remote-sensing.inrae.fr/

https://www.researchgate.net/project/SMOS-IC-2